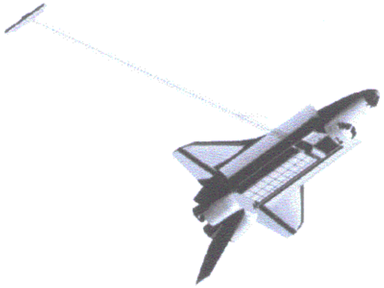
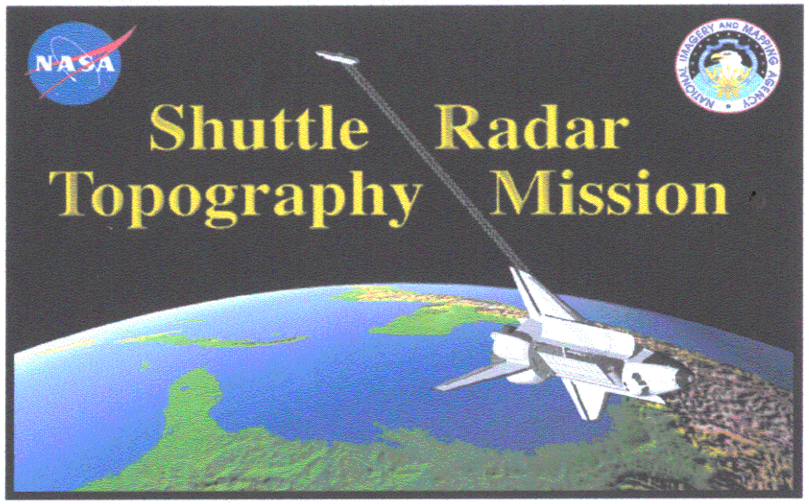
SRTM Metrology System: Flight Results





26 July 2000

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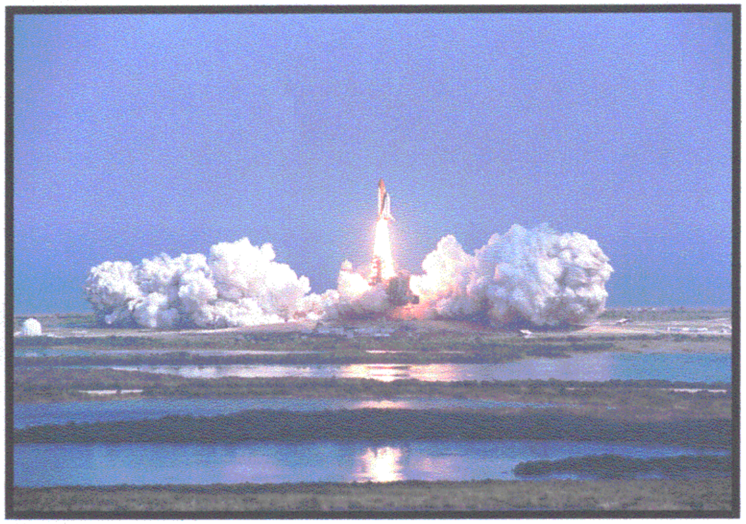

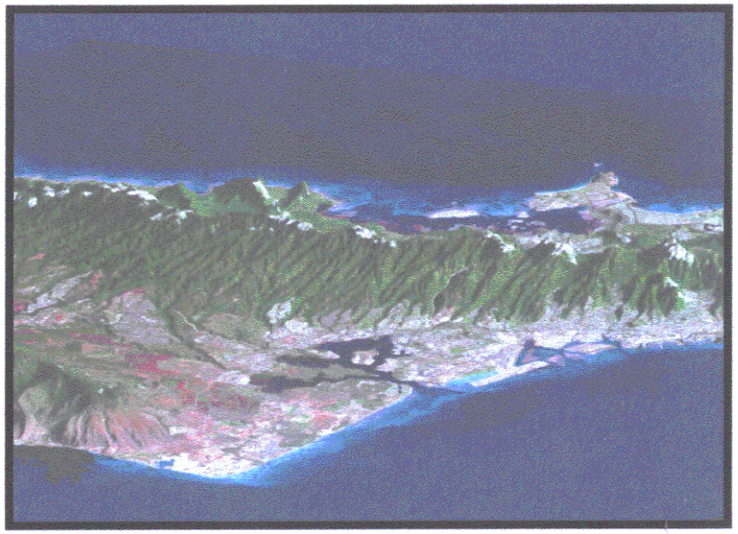

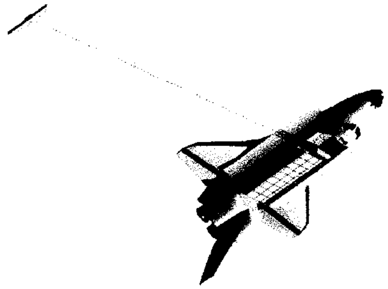

Agenda

- Abstract
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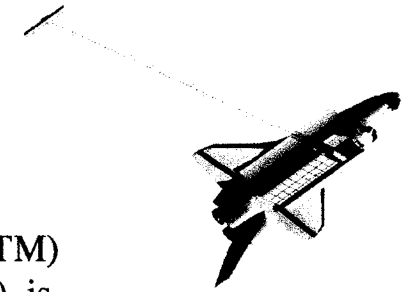
  - Height Reconstruction
- Attitude & Orbit Determination Avionics (AODA) Requirements
- AODA System Overview
- Flight Performance Assessments
  - Star Tracker/IRU (gyros)
  - Metrology Camera
  - Rangefinder
  - GPS
- Summary & Lessons-Learned

SRTM Metrology System: Flight Results



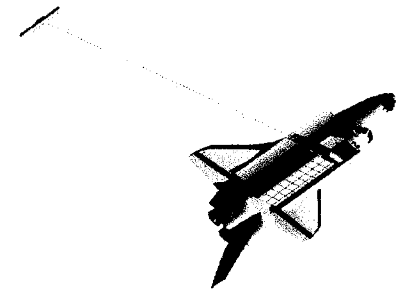
Abstract (abbreviated)

- An assessment of the inflight performance of the Shuttle Radar Topography Mission (SRTM) Metrology System, also known as the Attitude and Orbit Determination Avionics (AODA), is presented.

- The assessment is based on analysis of raw sensor data obtained during the mission.

- Initial indications are AODA met, and in many cases, surpassed its accuracy requirements, the most critical being:
  - baseline inertial attitude (roll angle) knowledge: 9 arcsec (1.6 sigma)
  - baseline length knowledge: 2 mm (1.6 sigma)
  - platform height/position knowledge: 1 meter (1.6 sigma)

- However, post-processing of the AODA data and calibration/validation with radar ground truth is still in progress. Any final conclusions await completion of this effort.



SRTM Summary

- Mission Objectives
  - acquire data over 80% of Earth's land mass (60 deg N to 58 deg S latitudes) and produce topographic products with 30 m x 30 m spatial postings with ≤16 m absolute vertical accuracy and ≤10 m relative vertical accuracy at the 90% (1.6 σ) level

- Sponsors
  - NASA, National Imagery and Mapping Agency (NIMA, DoD), German Aerospace Center (DLR, Deutsches Zentrum fur Luft- und Raumfart e.V.)

- Implementation
  - Flown on STS-99, Space Shuttle Endeavor 11-22 February 2000
  - Fixed Baseline Interferometric Synthetic Aperture Radar (IFSAR) at two wavelengths (C- and X-band)
  - 3 year development/operations phase & 2 year data processing phase
  - 4 major flight components:
    - C-band radar (C-RADAR)
    - X-band radar (X-SAR)
    - 60 meter deployable mast and mechanisms (SMS)
    - Metrology/attitude/orbit determination avionics (**AODA**)

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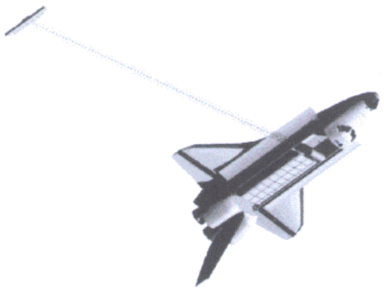
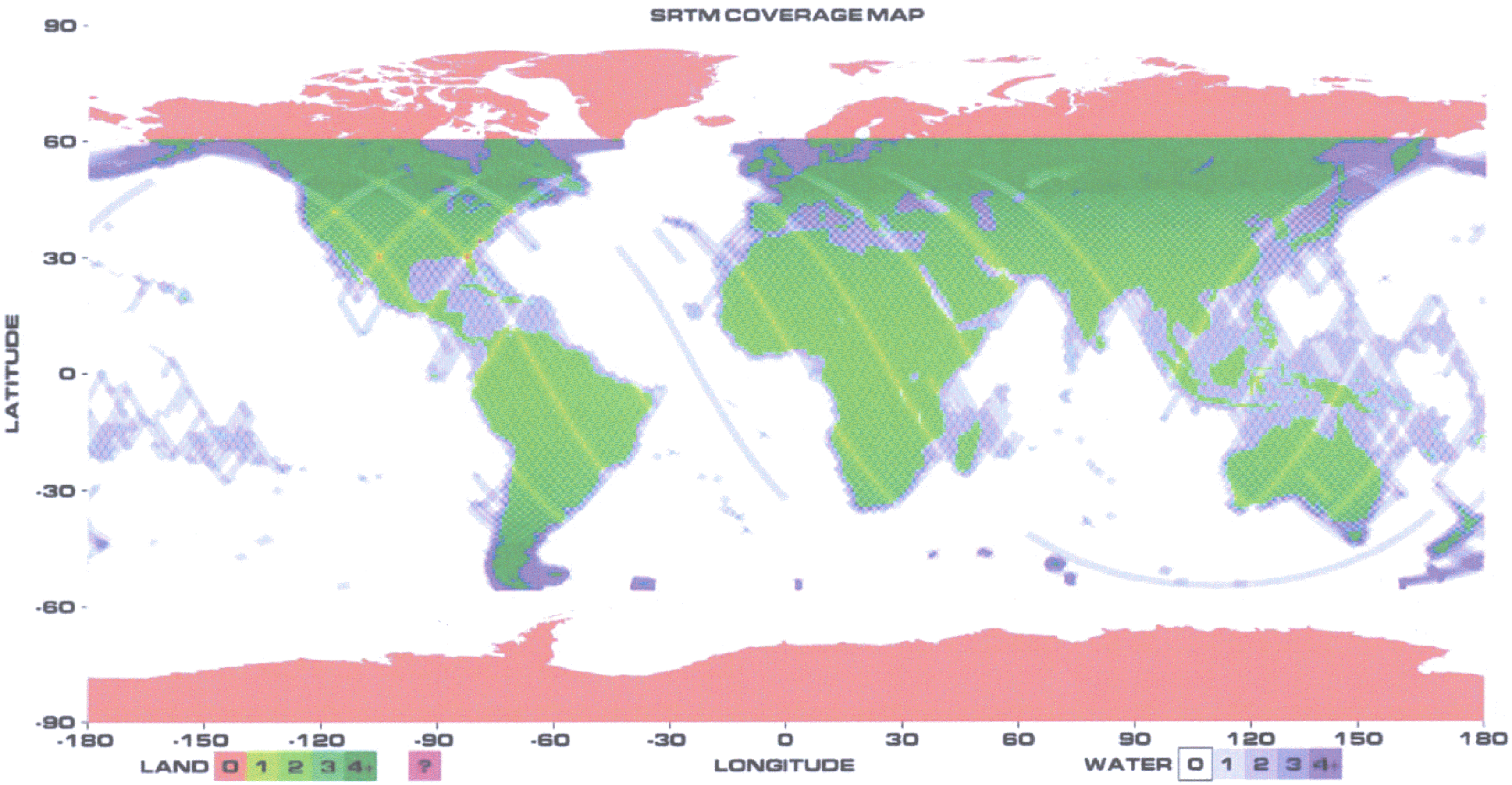
SRTM Metrology System: Flight Results



SRTM C-Band As-Flown Ground Coverage

99.96% of all land between +/- 60° latitude imaged once
(90% imaged twice)



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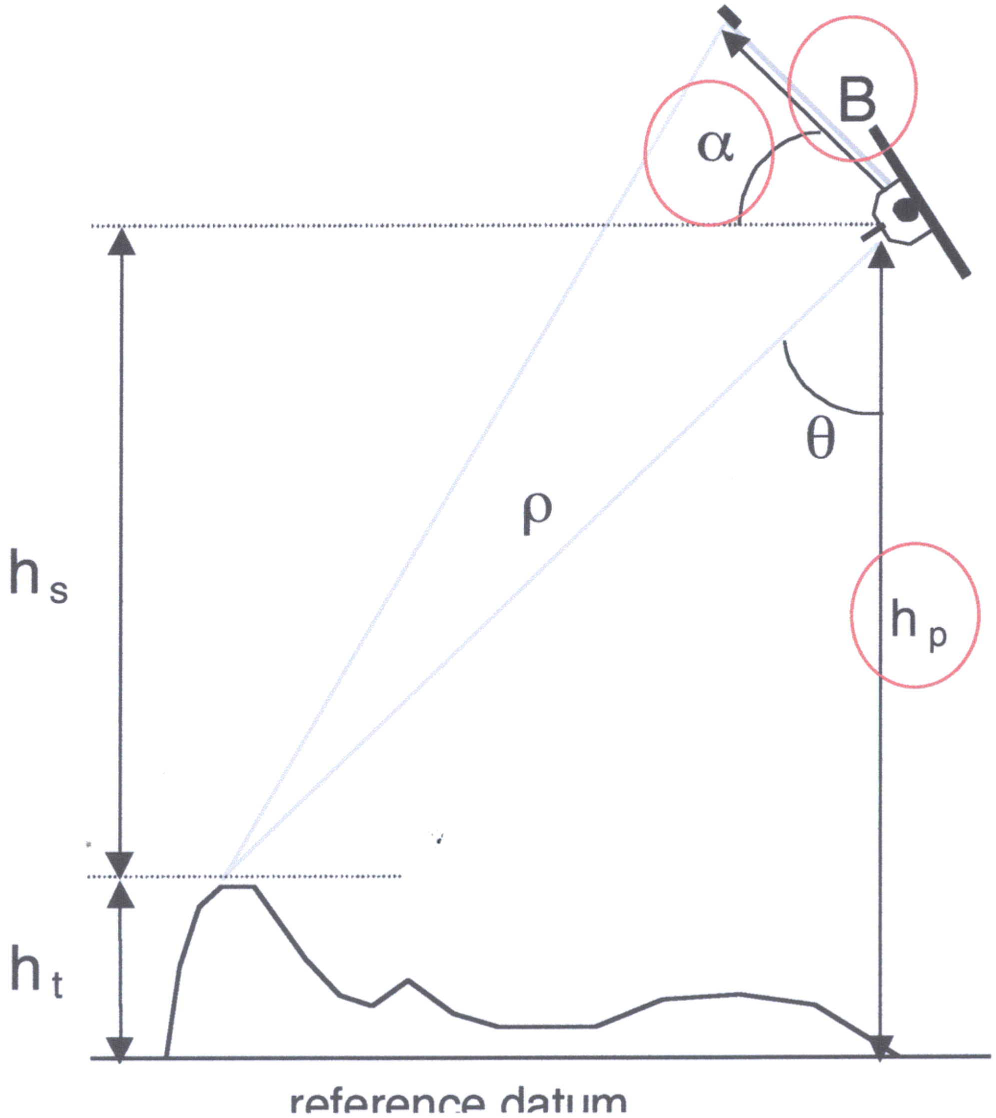
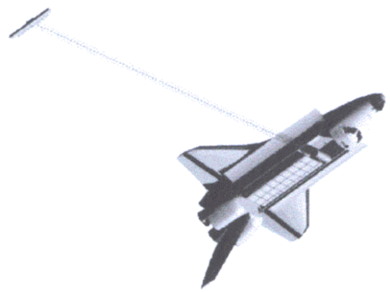
SRTM Metrology System: Flight Results

Height Reconstruction





1) use GPS to measure hp
2) use IFSAR to measure hs
3) ht = hp - hs

$$hs = \rho\cos(\arcsin(\lambda\phi/2\pi B)+\alpha)$$

Where

B = baseline length

α = baseline roll angle

ϕ = phase shift

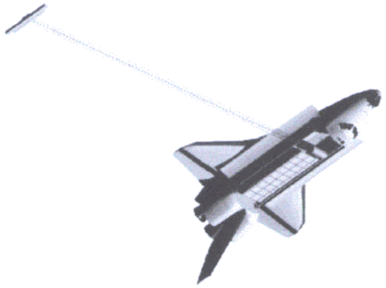
ρ = slant range

λ = wavelength

Measurements provided
By the Attitude & Orbit
Determination Avionics (AODA)

SRTM Metrology System: Flight Results

AODA Key Requirements (1.6σ)



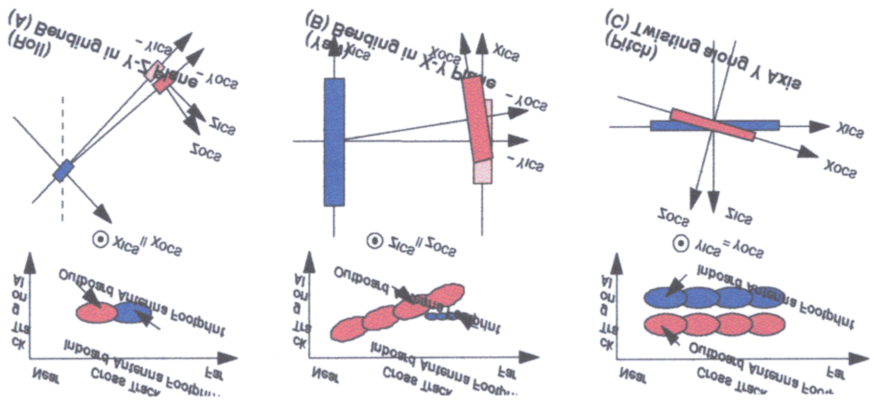
•Baseline & Platform Knowledge (to map Earth's topography to 10 m accuracy)

- baseline attitude (total inertial): 9 arcsec
- baseline length: 2 mm
- platform height: 1 m
- master time-base (relative to radar): 100 μs
- mostly post-flight

Note: most of the AODA accuracy requirements are in a *relative* sense (i.e., stability and noise only) - systematic errors (biases) will be removed in post-processing using radar calibration sites

• Mast Deployment & Antenna Alignment Verification (for shuttle/astronaut safety & radar performance)

- mast tip position: 5 mm
- antenna orientation: 0.03 deg
- real-time onboard display



• System Identification (for shuttle/astronaut safety & system performance)

- identify mast modal frequencies to < 10%
- verify mast model (damping, amplitudes, etc)
- near real-time response (to optimize shuttle ACS)

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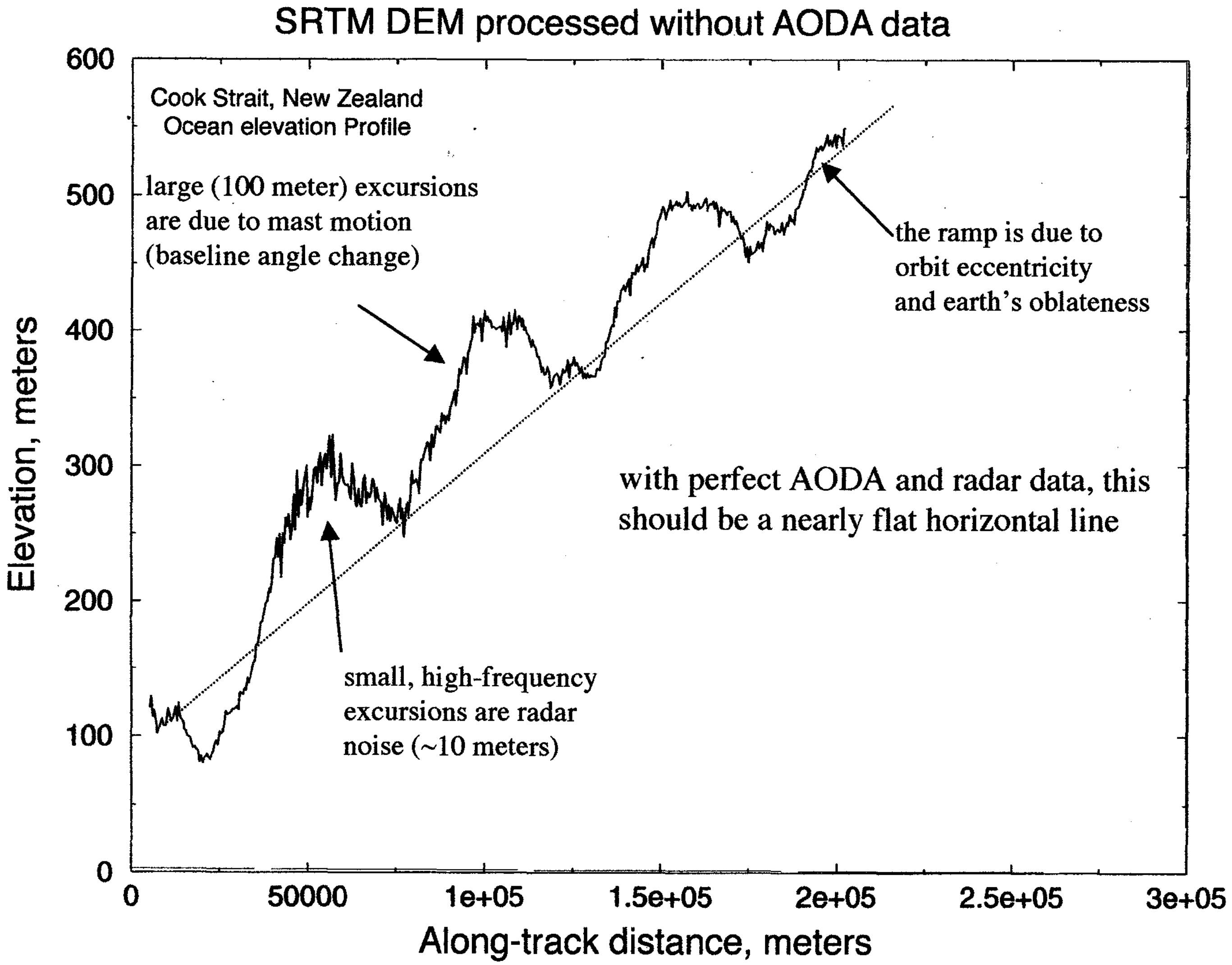
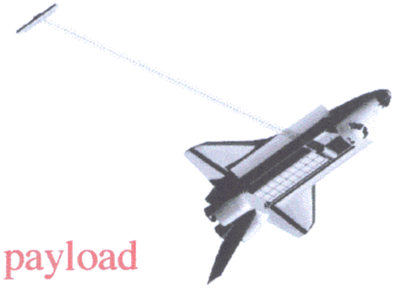
SRTM Metrology System: Flight Results

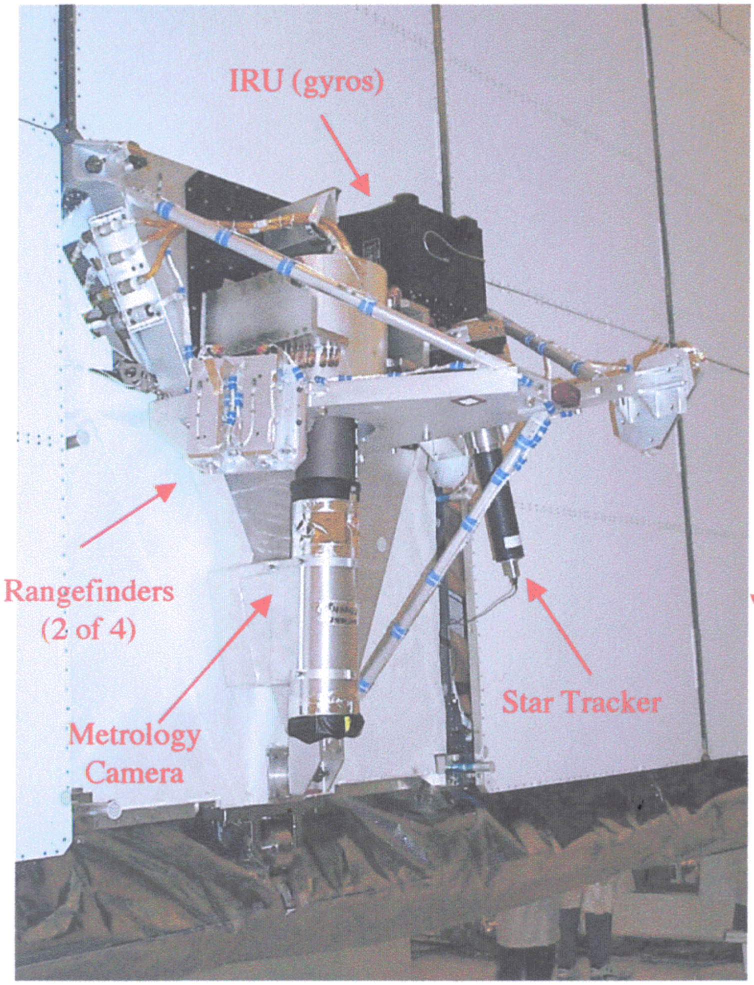
Illustration of the importance of AODA metrology data on SRTM height accuracy (ocean calibration data-take)



SRTM Metrology System: Flight Results



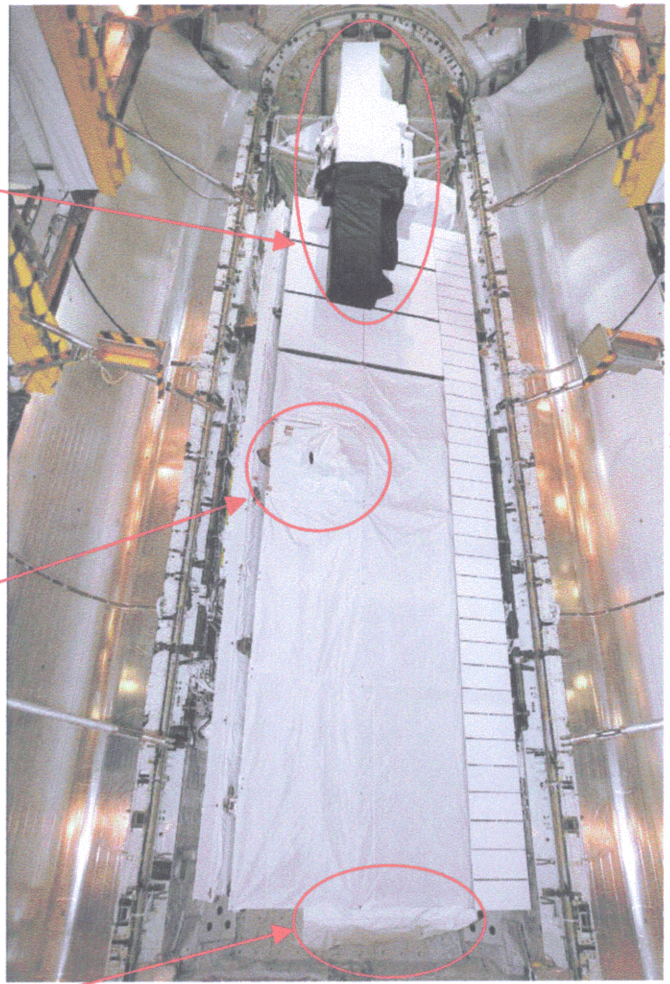
Detail view of sensor panel



SRTM in the shuttle payload bay at the launch pad

AODA optical targets & GPS antennas (on outboard antenna)

AODA optical sensor panel



20 meters

AODA electronics

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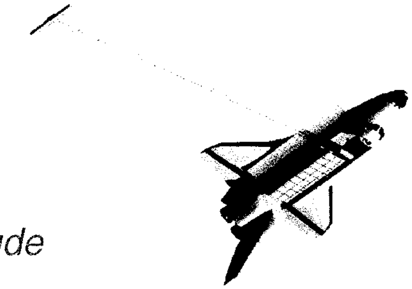
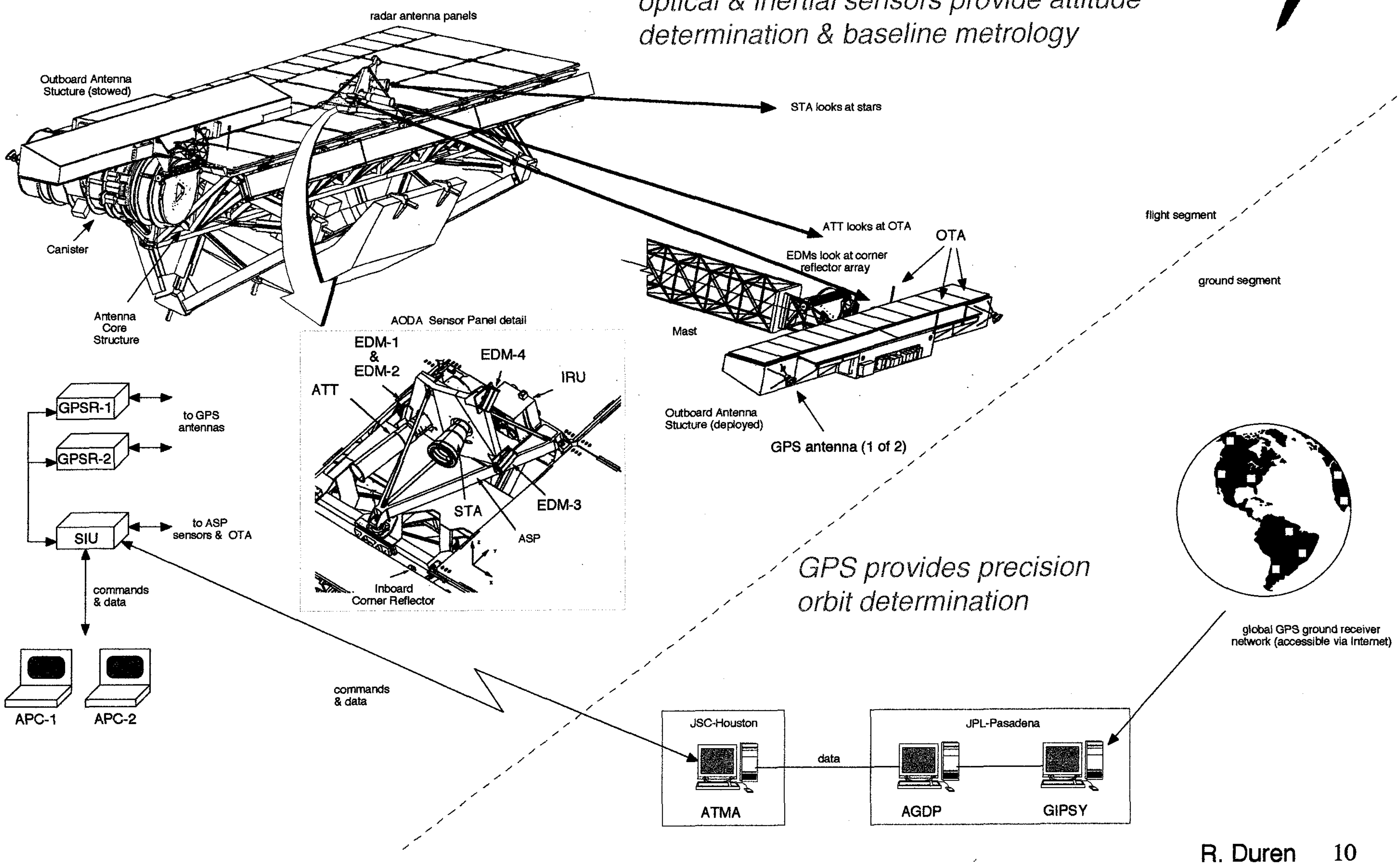
SRTM Metrology System: Flight Results

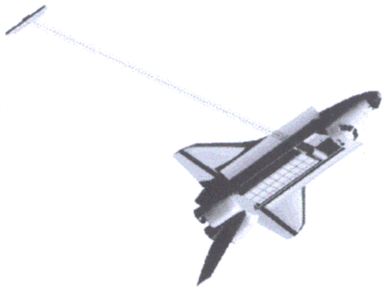
System Operation Concept

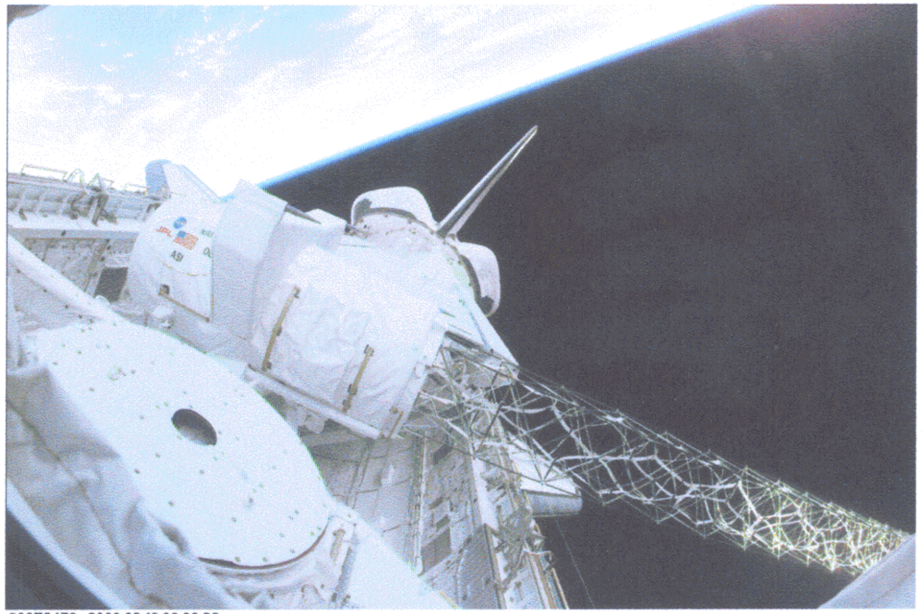




SRTM Metrology System: Flight Results

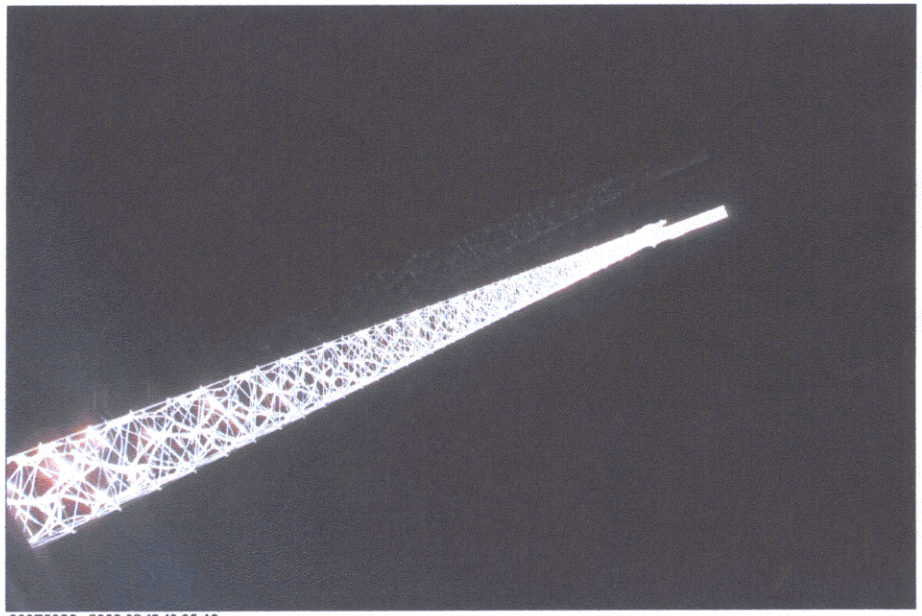
SRTM In-Flight Configuration
(60 meter mast deployed)





S99E5476 2000:02:16 06:09:32

Payload Bay (AODA Sensor Panel in center)

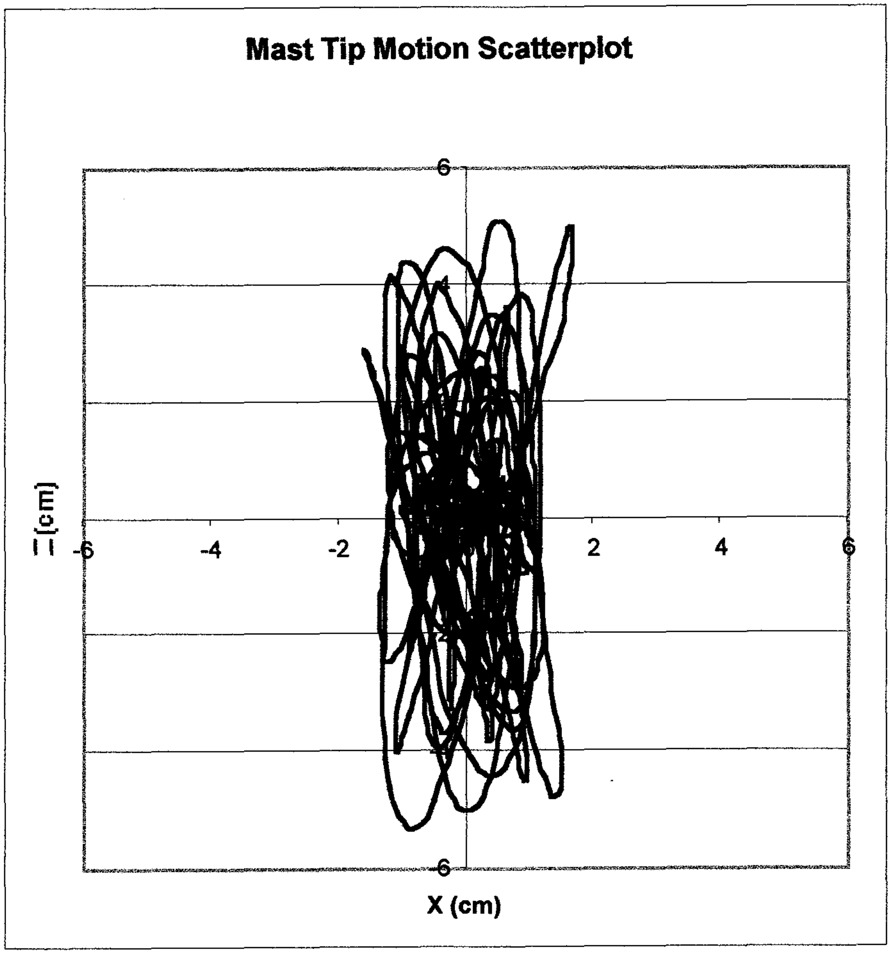


S99E5033 2000:02:13 10:05:46

Outer portion of Mast & outboard antenna

SRTM Metrology System: Flight Results

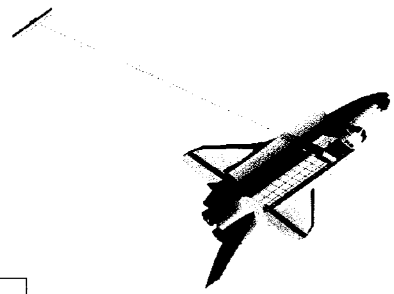
Typical Optical Target Dynamics (Mast Tip Motion)

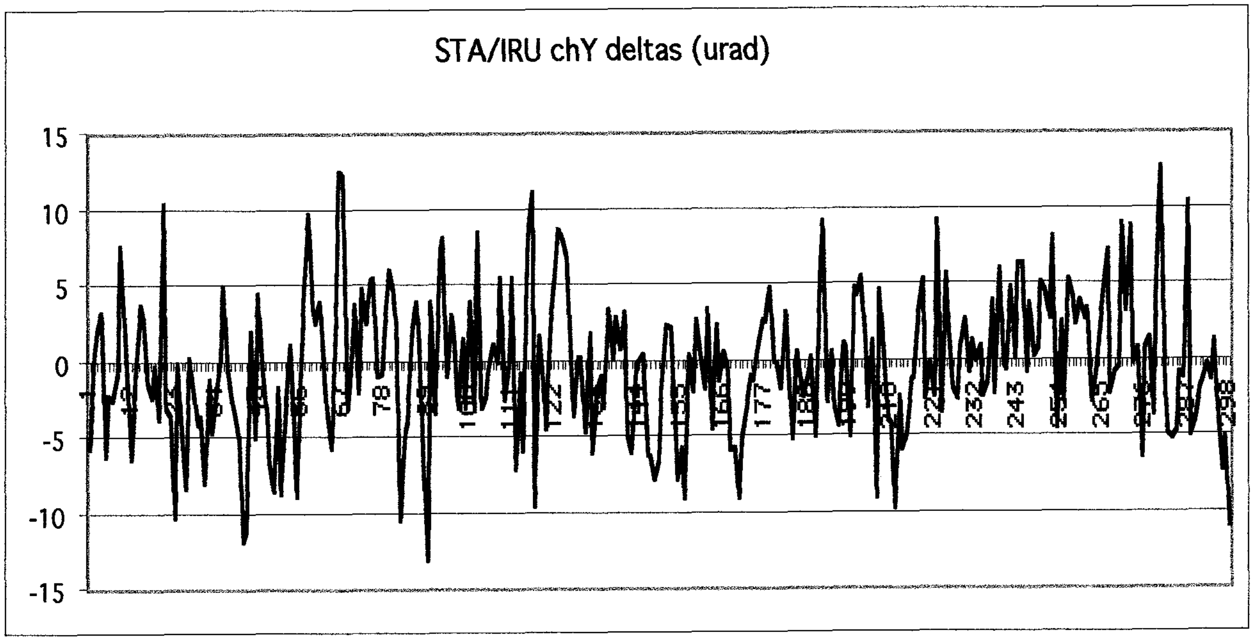


the observed mast motion is due to a combination of shuttle attitude control thrusters and astronaut crew disturbances (milli-g level accelerations)

SRTM Metrology System: Flight Results

Star Tracker & IRU (gyro) flight performance assessment





Star Tracker incremental angles were differenced with contemporaneous IRU (gyro) incremental angles

This indicates star tracker relative RMS (1 sigma) accuracy is about 4.7 urad (1 arcsec)

Incremental angles from redundant IRU gyro axes were also differenced to confirm IRU relative accuracy of approximately 1 arcsec (1 sigma)

Note: Star Tracker measurements (with contribution from IRU) provide the inertial component of the interferometric baseline angle (i.e., this error is basically RSS'd with that of the Metrology Camera)

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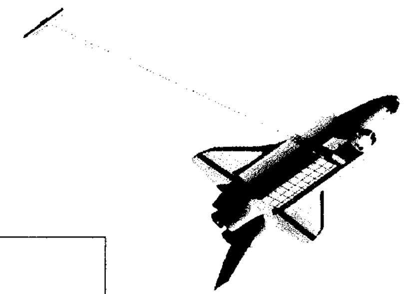
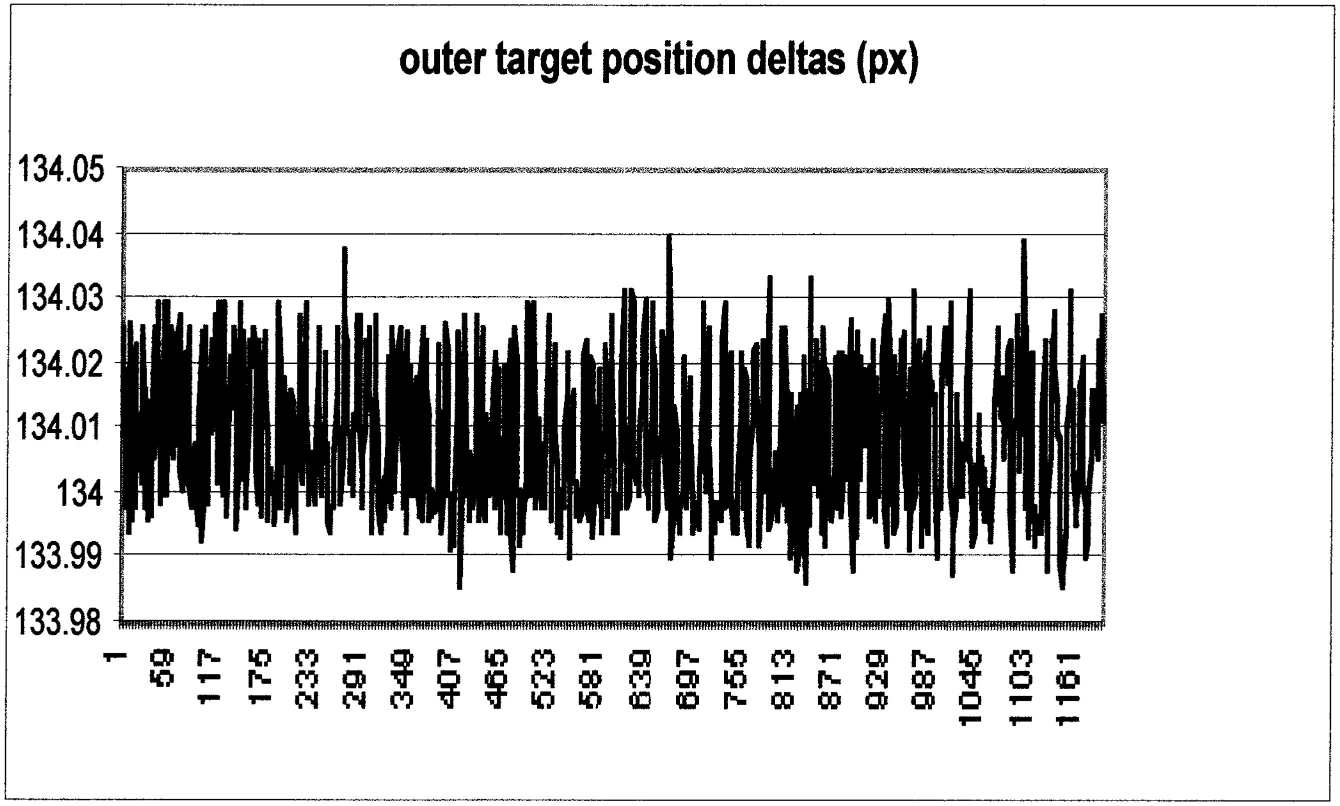
SRTM Metrology System: Flight Results

Metrology Camera flight performance assessment

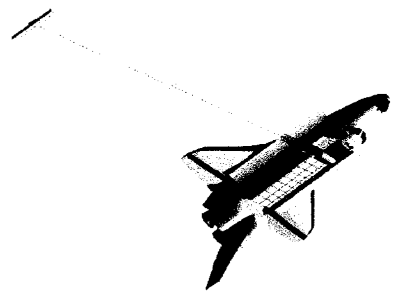




Position deltas were computed between the outer optical targets on the outboard antenna - this provides insight into Metrology Camera relative accuracy

Indicates Metrology Camera relative RMS (1 sigma) accuracy is about 0.007 pixels or 0.2 arcsec

Note: Metrology Camera measurements provide the "local" (mast-dominated) component of the interferometric baseline angle (i.e., this error is basically RSS'd with that from the Star Tracker)



Rangefinder & GPS performance

- Precise in-flight assessments of rangefinder accuracy were not feasible
  - the only independent sensor (metrology camera) has too much noise in range axis to confirm rangefinder accuracy (need sub-mm precision)
  - However, all indications were the rangefinders performed as expected (no noise was apparent - at least not at the few mm level)
  - This, combined with our preflight tests which confirmed sub-mm accuracy for the rangefinders, gives us high confidence that they met their 2 mm accuracy requirement in-flight
  - Post-flight data processing and calibration with radar ground truth sites should confirm this

- GPS position accuracy appears to be at or below the 80 cm level per axis (1.6 sigma)
  - Correlated receiver outages impacted about 5% of the data-takes during the mission
  - However, post-flight data processing (reduced dynamic technique) was sufficient to smooth through the outages while meeting the 1 meter requirement
  - Additional validation by radar ground truth is required to confirm this assessment

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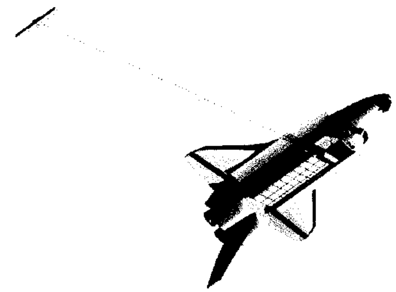
SRTM Metrology System: Flight Results



AODA Flight Performance Summary (1.6σ) †

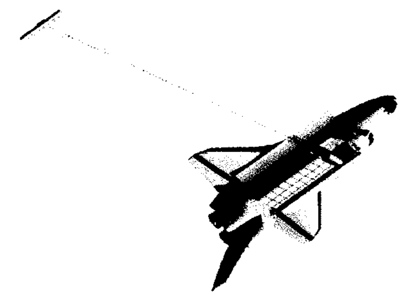
	Required	Observed	
Baseline roll angle (α)	9	3	arcsecs
Baseline length (B)	2	<2	mm
Platform position (h_p)	1	0.8	m

this is so good because of the outstanding performance of both the Target Tracker (0.3 arcsec observed vs 1.3 arcsec required) and Star Tracker (4.8 arcsec observed vs 16 arcsec required)*

If validated, the observed AODA performance could result in a significant improvement in overall SRTM height accuracy (perhaps several meters) - should know in a few months

† based on in-flight analysis of AODA raw sensor data; not yet validated by feedback from radar ground data processor

*Star Tracker worst-case performance (during H20 dumps) shown here; it was actually better 75% the time (typically 1 arcsec, 1σ)



Summary & Lessons-learned

- AODA appears to have met, and in many cases surpassed, the requirements
- Post-flight data processing is in progress to confirm the final accuracy using feedback from radar calibration (ground truth) sites
- Much of the AODA h/w is destined for re-use on other flight projects:
  - Rangefinders (separated spacecraft optical interferometer - ST3)
  - GPS receivers (earth orbiters)
  - Star Tracker (Mars program)
- AODA was a very fast-paced development effort with a limited budget yet it successfully served as a critical component of a major spaceborne instrument
- Similar systems can be successfully implemented in the future, provided:
  - Extra care is taken during early design phase to model and analyze all error sources
  - Significant design margins (particularly in performance areas) are necessary with systems of this caliber
  - Project planning should carefully consider post-processing calibration and validation efforts and assign costs and schedule accordingly